

Bebras in the Digital Game <Captain Bebras> for Students' Computational Thinking Abilities

Yan-Ming CHEN*, Ju-Ling SHIH

Graduate Institute of Network Learning Technology, National Central University, Taiwan

*peter880118@gmail.com, juling@cl.ncu.edu.tw

ABSTRACT

Bebras is widely known and used to enhance and examine students' computational thinking abilities. In order to make the testing process more intriguing, this study developed a digital game <Captain Bebras> with historical narrative background. This study aims to examine elementary school students' computational thinking abilities playing the game. The digital game simulates the historical events of the Great Voyage time with a map showing various tasks that the player has to perform with computational thinking abilities. Eight themes were classified by Bebras International Computational Thinking, including abstraction, logics, data analysis, decomposition, algorithms, simulation, system evaluation, and generalization. The core theory of each theme is integrated into the game stages, and the content of the Bebras Challenge is also used as the source of the tasks and the scoring base. By comparing students' gaming results with the traditional Bebras Challenge tests before and after the digital game, the researchers investigate students' improvement of their computational thinking abilities and the usefulness of <Captain Bebras>.

KEYWORDS

Computational Thinking, Bebras, Game-Based Learning, Digital Game

1. INTRODUCTION

Computational Thinking (CT) is an indispensable quality in the 21st century (Wing, 2011). Due to the popularization of computers and information, the speed of people's information exchange and problem solving has been greatly improved. It becomes essential for people to keep up with the pace of technological evolution. Therefore, Wing (2006) proposed that CT is a basic skill for everyone and many countries are integrating CT in education.

The United Kingdom added computational thinking to its national syllabus in 2012 (GOV.UK., 2014); Singapore called computational thinking a "national competency"; and the Computer Science Teacher Association (CSTA) proposed a K-12 computer science curriculum in 2016. Computational thinking is listed as one of the five core concepts in the standard. And then US President Barack Obama founded the "Computer Science for All" program (Obama, 2017) to give American primary and secondary school students more knowledge in computer science.

(<https://compthinking.csie.ntnu.edu.tw/>)

Combining the syllabus plans of various countries in the world, it can be seen that computational thinking is also increasingly valued and important. The "Information Technology" in our syllabus is also based on computational thinking, hoping to cultivate students' logical thinking,

systematic thinking and other computational thinking, and to improve the application of computational thinking and problem-solving skills through implementation. In addition to information technology learning in the formal system, the connection with international computational thinking-related activities can also be an important learning inspiration. Therefore, Taiwan has also implemented the "Computational Thinking Promotion Program" for many years, and actively carried out through various channels. Teachers There are empowerment studies, and related activities such as challenges and camps held with Bebras International Computational Thinking for students.

(<https://compthinking.csie.ntnu.edu.tw/>)

In this study, data will be collected to analyze for the following research questions:

1. Does the game <Captain Bebras> improve learners' conceptual understanding of Bebras Computational Thinking questions?
2. Does the game <Captain Bebras> improve learners' computational thinking performance?
3. What is the learner's overall satisfaction with the game <Captain Bebras>?

2. LITERATUR REVIEW

2.1. Computational Thinking

Computational Thinking means that students use specific strategies to solve problems or understand situations (Selby et al., 2014). It can be seen that this way of thinking is most focused on logic and systematicness, so CT is often used in science, or the integration of knowledge and information with logical judgment, such as the Lightbot game of (Peel & Friedrichsen, 2018) and Scratch programming learning activities, allowing students to visualize the modeling process of mRNA in biological science, and emphasize the five CT concepts of algorithm, abstraction, iteration, branching, and variable in learning.

Computational thinking is not only an ability related to science or information courses, but also other subjects as a way of thinking. It has characteristics such as using computers, data, or modeling to identify, analyze, and implement solutions. It is to help students clarify the logic of problems in a more effective way (Bocconi et al., 2016).

Other than in specific disciplines, computational thinking can be used in every place where there are problems to be solved. Kuo et al. (2020) designed a board game that simulates city life, and added time and money to the game. In the end, it was found that even in the absence of electronic products, or the absence of discipline-related themes in the



board game, students' CT abilities were improved with the board game.

Therefore, computational thinking is a problem-solving process. It uses logical processes such as decomposition, thinking, logic, and algorithm to produce solutions. When we encounter problems in life, we will try to disassemble the problem, find elements of small problems, abstract them into rules or principles, and then list various algorithms that can help to achieve goals. The purpose of writing programming languages is to perform computational thinking to solve problems.

2.2. Bebras

Bebras was conceptualized by Valentina Dagiene of Vilnius University. Bebras means "beaver" in Lithuanian, and refers to the prospect of having the students to study hard like beavers to achieve their goals with the intentions of diligence, intelligence, liveliness, and challenges.

The Bebras Challenge started on September 25, 2004, and is held globally in the International Bebras Week in mid-November every year. Since then, more European countries have joined, and Taiwan has officially participated in 2012. The Bebras Challenge hopes that the students participating in the competition can apply computational thinking to solve problems in their lives, so most of the questions are designed to be situational questions, and the operational thinking is divided into eight themes corresponding to the questions of the challenge (<https://www.bebas.org/>). (Figure 1)

1. Abstraction: Identify and extract relevant information to define the subject, simplifying things by removing unnecessary details.
2. Logic: Prediction and analysis to help understand things to clarify facts.
3. Analyze data: observe and understand through the collected data.
4. Decomposition: Decompose the problem into smaller and understandable problem content.
5. Algorithm: Create a logical flow of steps to use to solve a problem.
6. Simulation: Build an environment model similar to the real world.
7. Systematic evaluation: make judgments objectively and systematically.
8. Generalization: After observations, try to build rules to predict outcomes.



Figure 1. Eight Bebras CT aspects

From the statistics of the number of applicants for the Bebras Challenge, it can be seen that applicants in each group increase year after year. The latest year of 2021, it broke the record of 217,000. Among them, the Cadet group, referring to the seventh and eighth grades of middle school, is the largest group among all. Thus, the popularity of computational thinking education has been growing. Three goals of the Bebras Challenge are defined as follows. (<https://bebras.csie.ntnu.edu.tw/>)

1. Stimulate students' interest in learning information science. Bebras Challenge not only helps teachers to understand students' computational thinking ability, but also hopes to introduce the basic concepts of information science to students through situational tasks to stimulate their interest in learning. It is to let students understand that the application of information science concepts can be seen everywhere in life. The problem-solving and reasoning method can also improve students' motivation and enhance their ability of high-level thinking.
2. Improve students' ability to use computational thinking to solve problems. Bebras Challenge uses life situations such as family life, group cooperation, work arrangements, etc. to guide students to think and solve problems. The questions focus on computational thinking and problem-solving skills that only basic knowledge is required. Through the questions, students can understand that many problems in life can be solved by computational thinking.
3. Reduce students' fear of information science. Bebras Challenge concretizes abstract information science knowledge and presents it in situations that will be encountered in daily life. Thus, students who have not had information science education can also use their logic, induction, reasoning, and operations skills. On the other hand, the content of the questions is interesting which helps reduce students' anxiety about information science learning.

2.3. Digital Game-Based Learning

Technology products have indirectly affected educational models due to its convenience, multimedia effects, and fun. Digital game-based learning has brought learners strong motivations to learn and enhance students' attention more than ever before (Becker, 2007; Pivec, 2007).

By integrating knowledge from the textbooks into the game, tasks can provide students a simulated scenario with situations and stories that enable students' acceptance of knowledge and learning motivation (Chen & Lin, 2016).

Innovative game-based learning includes physical board games, STEM or robotics and other technology-integrated games, such as an interdisciplinary board game designed by Shih (2017) using the historical context of the Age of Discovery, also extended to integrate robots to enhance students' CT skills.

Game-based learning is not necessarily limited to the application of physical games or disciplines, but also strategies, question-answering, and feedback mechanisms are added to the game (Rojas-Mancilla et al., 2019). Therefore, digital games have been applied to many studies. For example, the game system TAPASPlay (Turchi et al., 2019) combines digital games with computational thinking. It is found that learners can increase their interests in computational thinking through games. Sobrino et al. (2020) designed a game system called Robotic, which uses real-life roads and traffic signs to simulate the real-world environment in the game, and promotes the cultivation of primary school students through various tasks in the game. Interest in computational thinking, and learning program logic, etc.

However, learning is not a cure-all, and learners may not necessarily feel the improvement of their own abilities or the application of knowledge after they play a game. For example, Shih (2016) used Robotic Game to analyze the code path and found that after multiple rounds of play, the learners' performance of game mechanics and operational thinking tended to be stable. Only players can really use their own experience to think, or effectively apply resources and strategies to the game.

3. GAME DESIGN

3.1. Game Mechanism

The design background of "Captain Bebras" comes from the 16th century era of great voyages. Magellan set sail from Spain in search of the spice road. Its story setting is inspired by our research team's past interdisciplinary history board games (Huang et al, 2019) , At that time, a large-scale world map (600x400cm) was used to fully present the territorial scope of the great voyage era in history, and students controlled robots through programming to gradually complete tasks with computational thinking.

In this study, "Captain Bebras" is a digital learning game that integrates Bebras' computational thinking. By referring to historical facts, Bebras' international standard of computational thinking and innovation of game elements, a series of tasks that simulate the real world are designed. The results were brought back to Spain as tribute. In the game, players take on the role of Captain Beaver on a voyage. In the process, they will encounter five different simulation problems, and gradually learn the corresponding topics of computational thinking through the game challenge process from simple to difficult.

The five missions in the game are designed according to the topic classification of Bebras with two missions in the simple level, two missions in the medium level, and one mission in the difficult level.

First, the player starts with Mission 1 — Direction Decoding (Figure 2). The player role-plays Captain Bebras, and moves to left, right, and forward according to the programming codes trying to find the correct treasure chest. This mission uses Algorithms and Systematic Evaluation skills in computational thinking.

After the player gets the treasure chest from the correct tree in the first mission, the player enters Mission 2—Spices Maze (Figure 3). In this mission, the player summarizes the order of spices in the limited scroll clue, and tries to find the correct order with his/her reasoning ability. Then, s/he can choose the correct maze map. The computational thinking skills used in this mission includes Logic, Algorithms, Simulation, Abstraction, Generalization and Systematic Evaluation.

After successfully obtaining the correct maze map, the player continues to Mission 3 - Spices Purchase (Figure 4). S/he needs to convert the complex maze map into intuitive numbers, and follows the sequence to various places for spices purchase. The computational thinking skills used in this mission includes Abstraction, Decomposition and Systematic Evaluation. When the player successfully completes the above three tasks, a staged transition screen will be given to bring s/he to another scenario.

After completing the first three missions, the player goes to a new story map to challenge more difficult levels, Mission 4 –Preference Combination (Figure 5). In this mission, the player sees a spice preference chart and chooses from it. Every spice can only be purchased in one country so s/he has to find the most favorable purchase combination before taking action onto the map of Mission 4 (Figure 6). This mission uses computational thinking skills including Algorithms and Systematic Evaluation.

In the end of the story, the player returns to Spain for Mission 5 - Tribute (Figure 7). and the player needs to use the spices purchased earlier to pay tribute to each castle in Spain by using the thinking of Euler Circuit. S/he would finally return to the start point and complete all the missions of <Captain Bebras>.

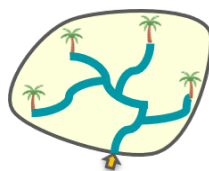


Figure 2. <Mission 1>



Figure 3. <Mission 2>

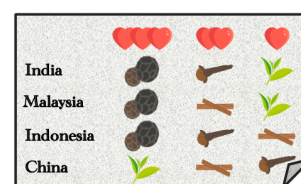


Figure 4. <Mission 3>



Figure 5. <Mission 4-1>

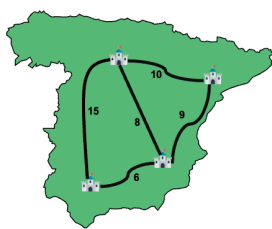


Figure 6. <Mission 4-2>

Figure 7. <Mission 5>

Each task in the game mission of this study is designed with reference to the Bebras computational thinking aspects, so the players' abilities can be analyzed accordingly. For example:

1. **Abstraction:** In Mission 2 and 3, the player extracts relevant information from the prompts and deletes unnecessary information to simplify the goal. For example, s/he has to find the correct maze map by extracting the information of the clues. The goal of mission three can only be completed by extracting information from the complex maze before transferring onto the map.
2. **Logics:** In Mission 2, the player uses reasoning to analyze the spice and order information before choosing the map.
3. **Data Analysis:** In Mission 5, the player observes all the path lengths in order to find the shortest path by using Euler circuit.
4. **Decomposition:** In Mission 3, the player breaks down the purchase problem into defining the order of spices, searching for spices on the map, and defining the path sequence in order.
5. **Algorithms:** In Mission 2, the player uses algorithmic commands to find which tree the treasure chest is in, then defines the spice codes for each path, and finally finds the matching path. In Mission 4, the player needs to find the best combination from the chart before acting on the map using the combination.
6. **Simulation:** In Mission 2, the player needs to use the limited amount of gold coins s/he has for the task just as in real life. In Mission 5, the player needs to consider the length of each path before finding the shortest path as in the real life choices.
7. **Systematic Evaluation:** In all Missions, the player needs to make judgments objectively with logical thinking in order to achieve the task goals.
8. **Generalization:** In Mission 2, the player observes the rules on the clues, establishes the order of spices, and generalizes the sequence for the application of the maze.

3.2. Gaming Process

Before the game, the teacher/game master (GM) starts a 10-minute game introduction, followed by a 15-minute pre-test. Then let the students start to play the game <Captain Bebras>. There are 5 tasks in each round of the game. It is estimated that one round of the game will take 60 minutes.

After completing the first round, a mid-term test will be conducted for 15 minutes. After entering the second round of the game, the teacher/ GM provides feedback to the students, about 10 minutes, and a post-test for 15 minutes, so the total game time is about three hours.

4. RESEARCH DESIGN

4.1. Research Process

<Captain Bebras> is designed for the Cadet group so this study aims to find 20 junior high school students who are between the ages of 13 and 15. A computer classroom will be used for the game-based learning class, and each student will use one computer individually. Students will be assigned an individual account for the game. The research process is shown in Figure 8.

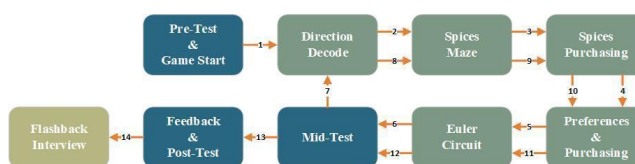


Figure 8. Research process for game-based learning with <Captain Bebras>

4.2. Research Data Collection and Analysis

In this game, students will need to:

1. Understand the game scene and game mechanism.
2. Complete game missions and express mission objectives.
3. Challenge the difficult tasks of the game.
4. Find out a strategy or solution to accomplish the task.
5. Infer what is learned from the game to life situations.

Wing (2006, p.33-35) suggested that "Computational Thinking is the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent." Therefore, when students play the game, the teacher should pay more attention to the students' problem-solving process instead of just the performances. In the research analysis stage, both students are invited to reflect on the gaming process, and understand in-depth the students' CT skills performances and problem-solving processes.

5. EXPECTED RESULTS

5.1. Bebras Performances

The game design ideas for all the levels in the game <Captain Bebras> are derived from the Bebras official exam questions. The design and research of gamification are carried out for the Cadet groups, referring to the seventh and eighth grades of middle school, classified by the official Bebras.

The first research question explored in this study is "Does this game <Captain Bebras> improve learners' conceptual understanding of the Bebras Computational Thinking

questions?" Therefore, Pre-test, conducted before playing <Captain Bebras>, mid-test following Level 3, and post-test while finishing all levels of <Captain Bebras> game. It is hoped that through the test at different times, learners' conceptual understanding to the Bebras computational thinking can be seen due to playing the game <Captain Bebras>.

The level of all the questions in the three tests are the same, but the question contents are not repeated. The calculation of the score and the test time are different from the official method, as shown in Table 2.

Table 2. Test method comparison

	Official Scoring Method	Scoring Method For This Study
Test Leveling	Simple, Medium, Hard	Simple, Medium, Hard
Total Questions	15	5
Examination Time	45 mins	15 mins
Lowest Score	60	0
Highest Score	300	100
Deduct Points	Yes	No

In the tests, the students' completion and scores will be emphasized (Figure 9). If the test completion rate of the pre-test is 40% and the post-test is 80%, it can be inferred that this game has missions that promote students to understand Bebras computational thinking better. Furthermore, if the student's pre-test score is 60 points and the post-test score is 100 points, it can be speculated that this game can promote students to understand the eight kinds of computational thinking of Bebras, and successfully use them in solving problems. Therefore, from the pre-, mid-, and post-test, if the learners have significant improvements in the degree of completion and accuracy, it shows that the students have a clearer understanding of the concept of Bebras computational thinking due to the game (Figure 10).

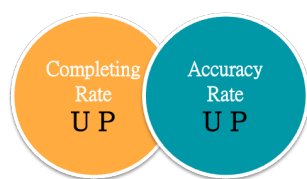


Figure 9. Test Aspects

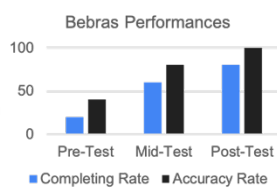


Figure 10. Test Scores

5.2. CT Performances

The second research question discussed in this study is "Does this game <Captain Bebras> improve learners' computational thinking performance?" The data source for this question is the same as that of the first research question using the three tests. Each official Bebras test question has

its corresponding standards for the classification of grades and the operational thinking ability of the test questions.

The operational thinking performance discussed in the second research question refers to Bebras' eight operational thinking abilities: Abstraction, Logics, Data Analysis, Decomposition, Algorithm, Simulation, Systematic Evaluation, and Generalization. Since each question will correspond to the multi-faceted CT abilities, we may observe multiple questions whether students have improved or changed the operational thinking ability in eight different aspects during the process of pre-, mid- and post-test.

This study expects that by playing the game <Captain Bebras>, learners can gradually improve their computational thinking skills so their completion rate and speed would accelerate.

5.3. Overall Satisfaction

This study expects that most of the learners like the game <Captain Bebras>, and are more interested and motivated in computational thinking because of the game-based learning. Through a series of missions that simulate real life problems in this research, learners can better understand the concept of computational thinking, and then apply computational thinking in real life situations.

With high improvement and satisfaction levels, it shows the potential of CT games.

6. CONCLUSION

In the 21st century, the advancement of information technology has led to changes in teaching methods. Schools no longer teach by rote learning, but use modern technology and novel learning models to help students build computational thinking skills. More and more attention is paid to students applying the knowledge they have learned to real life, so that students can learn all the time, both inside and outside of school.

Today's society places great importance on computational thinking. Computational thinking is a kind of thinking mode, especially for problem-solving. It is to apply logical thinking and finding solutions to complex problems through disassembly, methodical sorting, analysis, deduction, and other thinking methods in problem solving. Computational thinking can be used not only in disciplines, but also in daily life. Its essence is to decompose a big problem that is difficult to solve at once, but to dissect into small tasks to seek combinational solutions..

In this study, <Captain Bebras> guides learners to a digital game that simulates real world problems. Because Bebras computational thinking is incorporated into the game, learners are in the process of computational thinking when they try to decipher the tasks. In the end, after the game is completed, learners can apply them in real life more proficiently than in the past.

This study expects that the game <Captain Bebras> can increase learners' curiosity and motivation for computational thinking. Because of the incentives and novel learning modes of the game itself, it can be expected to include more

Bebras challenge questions into games to help children learn computational thinking. Digital games can also be designed to meet understanding levels for different age groups so as to tap the potential of each child's computational thinking.

7. REFERENCES

- Becker, K. (2007). Digital game-based learning once removed: Teaching teachers. *British Journal of Educational Technology*, 38(3), 478-488.
<https://doi.org/10.1111/j.1467-8535.2007.00711.x>
- Bocconi, S., Chiocariello, A., Dettori, G., Ferrari, A., Engelhardt, K., Kampylis, P., & Punie, Y. (2016). Developing computational thinking in compulsory education. European Commission, *JRC Science for Policy Report*, 68,15-17.
- Chen, H. R., & Lin, Y. S. (2016). An examination of digital game-based situated learning applied to Chinese language poetry education. *Technology, Pedagogy and Education*, 25(2), 171-186.
- GOV.UK. (2014). *National curriculum in England: computing programmes of study*. Retrieved July, 16, 2014.
- Huang, H. Y., Huang, S. H., Shih, J. L., Tsai, M. J., & Liang, J. C. (2019). Exploring the role of algorithms in elementary school students' computational thinking skills from a robotic game. In *3rd International Conference on Computational Thinking Education, CTE 2019* (pp. 217-222). The Education University of Hong Kong.
- Kuo, W. C., & Hsu, T. C. (2020). Learning computational thinking without a computer: How computational participation happens in a computational thinking board game. *The Asia-Pacific Education Researcher*, 29(1), 67-83.
- Obama, B. (2017). *Computer science for all*. Retrieved from WhiteHouse:
<https://www.whitehouse.gov/blog/2016/01/30/computer-science-all>.
- Peel, A., & Friedrichsen, P. (2018). Algorithms, abstractions, and iterations: teaching computational thinking using protein synthesis translation. *The American Biology Teacher*, 80(1), 21-28.
- Pivec, M. (2007). Play and learn: potentials of game-based learning. *British journal of educational technology*, 38(3), 387-393.
- Rojas-Mancilla, E., Conei, D., Bernal, Y. A., Astudillo, D., & Contreras, Y. (2019). Learning Histology Through Game-Based Learning Supported by Mobile Technology. *International Journal of Morphology*, 37(3),904-906.
- Shih, J.-L. (2016). Computational Thinking in the Interdisciplinary Robotic Game: the CHARM of STEAM. In S.-C. Kong & Harold Abelson (Eds.). *Computational Thinking Education in K-12*. Boston: MIT Press.
- Shih, J. -L., Huang, S. H., Lin, C. H., & Tseng, C. C. (2017). STEAMing the Ships for the Great Voyage: Design and Evaluation of a Technology integrated Maker Game. *IxD&A*, 34, 61-87.
- Schez-Sobrino, S., Vallejo, D., Glez-Morcillo, C., Redondo, M. A., & Castro-Schez, J. J. (2020). RoboTIC: A serious game based on augmented reality for learning programming. *Multimedia Tools and Applications*, 79(45-46), 34079-34099.
- Selby, C., Dorling, M., & Woollard, J. (2014). *Evidence of assessing computational thinking*.
- Turchi, T., Fogli, D., & Malizia, A. (2019). Fostering computational thinking through collaborative game-based learning. *Multimedia Tools and Applications*, 78(10), 13649-13673.
<https://doi.org/10.1007/s11042-019-7229-9>
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33-35.
- Wing, J. M. (2011). Research notebook: Computational thinking—What and why. *The Link Magazine*, 20-23.